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PROBLEMS OF ENERGY EFFICIENT GLAZING

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Problems of heat-shielding window apertures are discussed. The new heat-saving requirements and the ways of solving the problem using heat-saving glazing are specified. State-of-the-art types of glass and glazing units are decribed.

Since the moment when the area of glazing in some buildings began to compete with the area of the walls and in other buildings entire walls were made of glass, the requirements imposed on the properties of glass were modified and expanded. Indeed, most of the functions now fulfilled by glazing (the formation of the microclimate and hygienic environment of the interior) were previously executed by the walls. The significance of creating the interior microclimate can be defined in the following way: "The microclimate in public and residential buildings is the most important parameter of comfort and one of the crucial factors in increasing human life expectancy" [1].

There are no doubts that the problems of providing a comfortable environment for the interiors of buildings are going to receive much attention. The most important problems concerning this are: the prevention of temperature fluctuations on the internal surface of the glass in winter (prevention of negative radiation directed to the glass), improvement of lighting conditions, improvement of the sound-insulating properties of the glass, and reduction of heat losses occurring through the glass.

It is logical that along with the introduction of engineering methods for microclimate control in buildings, new types of glass with special properties will find wide application. The variety of these types of glass increases and their share in the total volume of glass production will keep growing.

Each type of glass possesses its own set of properties and has its own area of application. The knowledge of the properties of different types of glass used in construction ought to be the key to understanding its function in glazing. This is one of the main factors in selecting a type of glass for the windows of a particular building. The other factor is to formulate correctly the requirements for glass structures and materials.

The most important functions fulfilled by windows are as follows: provide for penetration of light, reduce heat losses in cold seasons, protect the rooms from outside heat in the summer under intense insulation; protect the interior from penetration of noise, dust, and outside air. In designing windows one should integrally solve all these problems, and the solutions in turn depend on the selection of the glass structure and the type of the glass used.

It ought to be noted that the architectural and construction requirements imposed on windows as an element of the building are traditional and in many cases outdated. The structure and outward appearance of contemporary buildings (rectangular spaces, lighting implemented mostly via vertical apertures, extremely rare use of upper lighting etc.) were formed at the border of the XIX and XX centuries. At present, energy problems have altered the vision of the structure of a building and its energy consumption level. The attempt to reduce heating expenses, which in countries with a moderate climate account for 30 to 50% of the total power costs, stimulated intense research over the world. As a result, new types of buildings originated.

The changes concerned not only the particular structures and materials used but the entire shape of the building, its layout, heating systems, ventilation, and lighting. All this resulted in the appearance of new non-traditional types of windows.

A review of buildings constructed recently showed that great attention is given to the shape of the building: such energy-saving shapes as a truncated pyramid, a cube, etc., are now selected.

The functions of windows in the new energy-efficient buildings are much wider. In some recent designs of public buildings, the windows and the canopies shading the light ap-

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ertures are arranged in such a way that in summer under the high position of the sun in the sky no direct solar radiation falls on the windows.

It was found that the most common technique, i.e., a simple increase in the number of glass panes in the windows, is not efficient enough. The contemporary version of improving the design of window apertures is represented by multiple glass units.

The use of heat-shielding glass is an efficient method for reducing energy losses via the light apertures. It also increases the temperature of the internal surface of the windows in winter, which helps to improve the hygienic situation.

In the rooms where low temperatures of the internal surface of windows are inadmissible, it is advisable to use the electrically heated windows.

For many years researchers, designers, builders and maintenance operators have been involved with the problem of protecting a building from excessive heat under the intense solar radiation in summer.

Construction glass with special properties allows penetration of ultraviolet radiation into the interior, reduction of overheating of the interior produced by radiant heat, prevents the discomfort that may arise in the immediate vicinity of the windows in the cold months, and reduces heat losses via light-transparent enclosures.

Ultraviolet-transmitting glass. The use of natural ultraviolet radiation acquires special significance in the construction of hospitals, kindergartens, schools and health resort buildings. It should be remembered that in large cities, the intensity of natural ultraviolet radiation is reduced considerably due to the significant pollution of the air with dust, soot, and other industrial emissions. Thus, in some industrial districts, losses of ultraviolet radiation run as high as 42%, and in residential quarters amount to 24%.

Besides, in the central and northern regions of the Russian Federation ultraviolet radiation is distributed very unevenly over the year. That nonuniformity is especially evident in the Far North, where for a few months during the polar night ultraviolet radiation is absent. This deficiency may result in disruption or weakening of certain functions of the human organism.

Architects often design large window surfaces in new buildings, yet when the usual silicate glass is used, such windows become an insurmountable obstacle for the biologically active component of solar ultraviolet radiation. This disadvantage can be avoided by using uviol glass.

Glass for sun-shielding glazing. The use of relatively large window areas in modern buildings may cause significant overheating of the premises if the light apertures are adversely arranged. In order to eliminate this negative factor, sun-shielding glass is used which includes heat-absorbing, heat-reflecting and neutrally colored glass. The very names of the glass types show that some of them absorb and others reflect a considerable portion of infrared solar rays. Neutral glass has reduced transmitting ability along the entire optical range of the solar spectrum.

Heat-shielding glass for heat-insulating glazing. In the areas located next to light apertures in modern buildings some discomfort may arise owing to negative radiation from the cold surfaces of windows and enhanced downward convective flows of cold air. This often results in catharral diseases, especially among children in kindergartens and schools and people whose work places are located in the immediate vicinity of the windows in the discomfort area.

In the cold seasons, due to the low temperature of the internal window surface, condensation and icing often appear on the glass, which is undesirable with respect to sanitary hygienic conditions and the lighting conditions in the interior. Finally, the low resistance to heat transfer in traditional window structures results in significant heat losses.

World construction practice, in addition to upgrading of the design of the casement in order to improve the heat shielding properties of light-transmitting structures, offers as well air-conditioned windows and glass with selective optical properties that reflect to a great degree energy in the long-wave infrared range (2500 – 50,000 nm).

In order to create an adequate microclimate in rooms with large window areas in the facades, it is necessary to provide for shielding of these surfaces from solar radiation. Air-conditioning systems (usually used for cooling in summer) are much more expensive per kilocalorie than heating systems. The sun-shielding design techniques adopted in Germany usually make it possible to give up air-conditioning without rejecting the large window surfaces which satisfy the requirements of the architects.

Heat-absorbing glass provides for somewhat lower heat protection than heat-reflecting glass and reduces the daytime illumination of the rooms in winter period.

Heat-reflecting glass provides for more efficient protection from heat radiation than heat-absorbing glass. It guarantees better illumination of interiors in the summer but does not provide for sufficient day illumination in the winter.

Sun-shielding glass ought to be recommended only in the case when its transmission of light is significantly higher than infrared transmission.

Shielding from the sun has to prevent overheating of the air in the room but should not reduce the illumination and its uniformity. It should not cause additional loads, or deteriorate ventilation and the architectural appearance of the building. The cost of maintaining sun-shielding devices should not be too high.

The use of *heat-reflecting films* applied to sheet glass is very effective. The film deposited on the glass reflects 80 – 90% of the heat energy radiated by the walls of the room which usually passes through the window into the street outside. The use of heat-reflecting film makes it possible to reduce significantly transmission of heat through the windows, increase their insulating capacity and reduce the cost of heating the building in the winter [2].

Heat transmission through windows is characterized by two components: heat-conducting and radiating. The heat-conducting component is the heat conductivity of the glass,

and the radiating component is the infrared radiation. Though ordinary window glass practically does not transmit radiation of more than 4 μm wavelength, yet this infrared radiation is absorbed by the glass and causes its heating. The warmer glass (namely, its outer surface) in turn becomes a source of heat radiation, and the heat energy is finally emitted outside. Heat-reflecting film is capable of retaining this energy (80 – 90%) inside the room.

It is obvious that the greater the share of heat flow implemented by radiation, the higher the efficiency of the reflecting film is. The heat-conducting component of heat flow can be reduced by suppressing air-to-glass and glass-to-air heat transmission. The most efficient method for such suppression is the use of double, triple and multiple insulating glass units. The space between two glass panes is hermetically closed and does not exhibit the air circulation typical for the interiors. Heat transmission from the first pane to the intermediate space and then from it to the second pane is reduced to such a degree that heat transfer by radiation comprises 60 – 70% of the total energy transfer in the double pane.

The heat-reflecting film in double panes is always oriented toward the enclosed space: it is either on the inner side of the outer pane, or on the outer surface of the inner pane. In the first case, the film reflects the radiation emitted by the warm inner glass into the enclosed space. In the second case the film functions as a low-emitting film; thanks to its low radiation coefficient, it reduces the amount of energy radiated by the inner pane in the same proportion as the reflecting film on the outer pane.

Table 1 shows the heat transmission factor U for different types of insulating windows. The width of clearance between the panes is 12 mm in all cases. It is seen that heat-reflecting film reduces factor U of the double pane by nearly half. Two reflecting films in a triple pane with a gas filler reduce U to 1.1 $W/(m^2 \cdot K)$ which is practically one third of the standard double pane.

The reduction of U depends on the film quality: the higher the reflecting capacity and, consequently, the lower transmission factor of the film, the less heat is transmitted.

The values of U were calculated based on the known values of the radiation coefficient (multiple insulating panes each 4 mm wide and the intermediate space 12 mm) and compared to the values of the energy balance measured during 4 heating seasons. The energy balance value is determined as heat losses through windows minus the energy input contributed by solar radiation.

Triple glazing without reflecting film has a better energy balance due to the higher U factor when located at the southern, eastern, or western sides compared to double glazing with the best reflecting film. This is attributable to greater transmission of energy into the room. The film also reflects the long-wave part of the solar spectrum that penetrates into the room in the case of triple glazing.

For the first two types of glazing located on the southern side, the energy balance is negative. This means that the heat losses are below the amount of heat transmitted through the windows into the room. On the northern side, on the contrary, the influence of solar radiation is not manifested, therefore double glazing with a reflecting film has a better energy balance than triple glazing without any film, which corresponds to the difference in the U factor values.

Double glazing with a radiation coefficient of 0.3 (i.e., 70% reflecting capacity) used on any side of the building exhibits the worst energy balance registered, and this agrees with the higher value of the U factor. It is interesting that the U factor improves as a result of application of the reflecting film on the second glass sheet of the double pane as well.

Thus, it is advisable to use heat-reflecting film mainly in double glazing where its effect is the most pronounced.

Double panes are mostly used in windows in the outer enclosing structures of a building for which thermotechnical properties are of primary importance. The heat-insulating capacity of the glass units is assessed by their resistance to heat conduction. The better this resistance is, the better the heat-insulating properties of the enclosure are. The heat-engineering parameters of multiple panes depend on the number of intermediate spaces and their thickness. Besides, a considerable effect on them can be exercised by the type of filling between the glass sheets, the radiation coefficients of the glass surfaces (especially the heat-reflecting ones), the angle between the multiple glass unit and the horizon line, and the material of which the cross-bars and enclosing frames are made.

Heat-reflecting glass types with a transparent coating are the most efficient for protection from solar radiation. They reflect the greater part of the radiant energy and become heated to a smaller degree, which facilitates their maintenance and enlarges their area of application compared to heat-absorbing glass [3].

There are two known types of heat-reflecting glass: the first type has a transparent coating made of the oxide of iron, tin, cobalt, chrome, nickel, and silicon deposited on the glass surface in the course of its manufacture, and the second type has a transparent coating based on silver, gold, copper, nickel and different metal alloys deposited on the glass surface using vacuum technology. Such types of glass are able to reflect both short-wave and the long-wave spectral ranges, therefore they can fulfill simultaneously both sun-shielding and heat-insulating functions: on one hand, they reduce the input of solar radiation into the room in summer time, and on the other

TABLE 1

Number of glass panes	Environment in the intermediate space	Reflecting film	Heat transmission coefficient, $W/(m^2 \cdot K)$
	Air	None	3,0
	Special gas	The same	2.6 – 2.8
	Air	Present	1.7 – 2.1
2	Special gas	The same	1.3 – 1.6
	Air	None	2.0 – 2.2
3	Special gas	Present	1.1

TABLE 2

Type of glass unit*	Heat transmission coefficient, $W/(m^2 \cdot K)$	Light transmission, %
Cappofloat	1.9	76
Insulite-K	1.65	82
Planitherm	1.7	78
Ordinary glass	3.18	83

* Design 4-12-4.

TABLE 3

Type of glass unit*	Heat transmission coefficient, $W/(m^2 \cdot K)$	Light transmission, %
"K-Glass"	1.8	75
EKO	1.9	72
"Ford Low-E-glass"	1.8	81

* Design 4-12-4.

hand, they reduce radiant heat losses through windows in winter.

Three-layer metal films attain at a maximum transmission in the visible spectrum range equal to 80 – 90%, like, for example, the film $TiO_2 - Ag - TiO_2$.

The industrial production of flat glass for construction is mostly based on the principle of magnetron cathode sputtering.

The cut glass panes are processed on a conveyor line with a capacity of about 500 thousand sq. m. per year. The size of the sheet is up to 3 × 6 m. The properties of the multiple glass units made of glass with a metal coating are given in Table 2.

The semiconducting film is usually deposited by the thermal decomposition method. The film is deposited directly on the glass-production line. The properties of the glass units made of glass with semiconducting coating are shown in Table 3, and the properties of the different glass types are given in Tables 4 and 5.

The heat transmission coefficient in ordinary transparent glass is 5.4 $W/(m^2 \cdot K)$, in the double pane it is reduced to 2.8 $W/(m^2 \cdot K)$, and in the double unit made of K-Glass it is 1.9 $W/(m^2 \cdot K)$. When the space inside the glass unit is filled with argon, the U factor drops to 1.6 $W/(m^2 \cdot K)$.

The U of triple glass for ordinary glass is 2.0 $W/(m^2 \cdot K)$, and in triple glazing made of Kappa Energy glass, it is improved to 1,5 $W/(m^2 \cdot K)$.

The U of a standard window with double glass is 3.0 $W/(m^2 \cdot K)$, and that of triple glazing is 2.0 $W/(m^2 \cdot K)$. The U of the elements of standard double glass units filled with argon and having selective glass amounts to 1.5 $W/(m^2 \cdot K)$, and that of triple units is 1.2 $W/(m^2 \cdot K)$.

Companies producing multiple glass units and wishing to improve the quality of their products can produce as their basic products double-layer elements with selective glass having a U at the level of 1.1 $W/(m^2 \cdot K)$, and triple-layer ele-

TABLE 4

Parameter	Transparent glass	Heat-absorbing glass	Heat-reflecting glass	
			metal film	semiconducting film
Ordinary glazing				
Light transmission of the visible spectrum, %	87	75 – 80	80 – 90	80 – 85
Transmission of complete solar energy, %	80	55 – 70	75 – 80	70 – 80
Heat transmission coefficient, $W/(m^2 \cdot K)$	5.6	4.5 – 5.4	2.8	3.0
Double glazing, design 4-12-4				
Light transmission of the visible spectrum, %	80	65	80	80
Transmission of complete solar energy, %	75	40	75	40
Heat transmission coefficient, $W/(m^2 \cdot K)$:				
intermediate space filled with air	2.8 – 3.0	3.0	1.7	1.8
intermediate space filled with argon	2.0	2.0	1.5	1.6

TABLE 5

Parameter	Transparent glass, intermediate space filled with		Heat-reflecting glass: Metal film, intermediate space filled with		Heat-reflecting glass: Semiconducting film, intermediate space filled with	
	air	argon	air	argon	air	argon
Triple glazing design 4-12-4-12-4						
Transmission of the visible light spectrum, %	72	72	60	60	68	68
Transmission of complete solar energy, %	67	67	54	54	64	64
Heat transmission coefficient, $W/(m^2 \cdot K)$	1.9	1.75	1.3	1.0	1.4	1.2

ments whose U corresponds to the coefficient of heat conductivity for the walls of light structures, i.e., 0.5 W/(m^2 · K),

An example of this is the new selective glass Planitherm Futur made by Saint-Gobain. It is a double insulating glass unit with U equal to 1.1 W/(m^2 · K), light transmission of 76%, and transmission of total solar energy of 58%. In the triple insulating glass unit, the U can be approximately 0.4 W/(m^2 · K).

At present, consumption of heat energy used to heat buildings in the Russian Federation is on average about 500 kW · h/m^2, which is nearly 4 times more than in Sweden or Finland (135 kW · h/m^2) in spite of the similar climatic conditions. (Data provided by the Ministry of Construction of the RF.) This results in an extremely high cost of maintenance of dwellings, already exceeding the financial capabilities of the population (nearly 1 million families in Moscow receive subsidies for utility payments).

Recently the Ministry of Construction of the Russian Federation and the Moscow Government adopted a series of documents with strict requirements for heat protection of buildings, providing for a system for supervising the fulfillment of these requirements. The corresponding measures intended to save energy are now being developed, without which housing reform would be impossible,

In implementing the new requirements for heat-saving technologies for buildings, the main problem consists in protection of window openings since up to 50 – 55% of the heat from the interior is lost through the windows. It is an integrated problem that cannot be solved without developing new window frames, new locks on casements, ventilation systems for interiors, and new types of glass. At the same time, a number of requirements related to the functional meaning of windows in buildings has to be taken into account:

normal natural lighting should be provided in the interiors, i.e., the light transmission coefficient cannot be less than the prescribed value;

insulation and normal ventilation have to be provided;

heat losses through the windows have to be reduced.

The optimum variant for the windows of buildings in Russia, in our opinion, is the use of glass with a heat-reflecting coating which permits, with relatively low expenditures, reducing the heat losses through windows 1.5 – 2-fold. There are several types of glass with heat-reflecting coating which satisfy all the requirements imposed and are produced industrially by foreign companies (in the Russian Federation such glass is not produced). A well-known grade is the K-Glass manufactured by Pilkington Inc..

At present, some experimental houses in Moscow are being built with maximum use of resource-saving technologies, which will make it possible to test in practice the efficiency of application of heat-reflecting glass, including K-Glass. The tests carried out at GIS joint-stock company confirmed the high service properties of this glass. The final results of the experiment will be known by the end of 1999.

The use of special glass instead of traditional glass will make it possible to save heat energy in standard dwellings constructed in the central zone of Russia without lowering the illumination of the rooms.

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